NEW MILLENNIUM PROGRAM

Technology Provider Workshop

Subsystem Technology Requirements

Quad Charts

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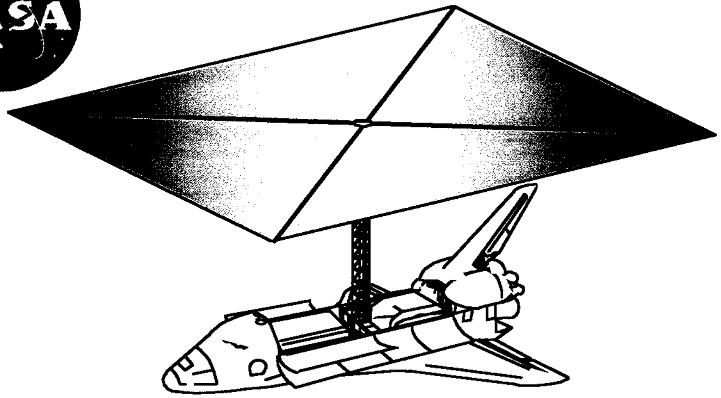
Solar Sail Deployment

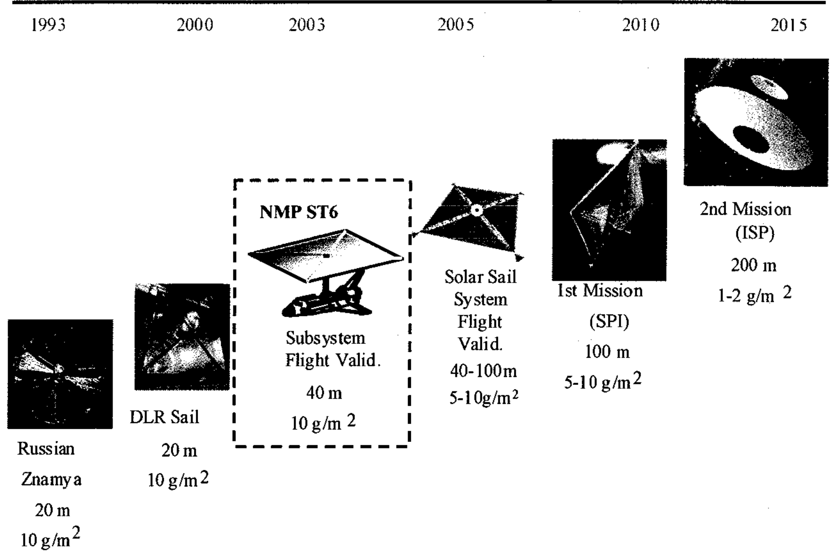


Characterization of Sail Deployment Structural Dynamics

Technology Requirements:
- Deploy 40m x 40m sail
- Areal density 10-15 g/m2
- Experiment mass < 150kg

State of the Art:
- Russia has deployed 20m sail
- DLR has developed prototype 20m x 20m sail

Solar Sail Roadmap

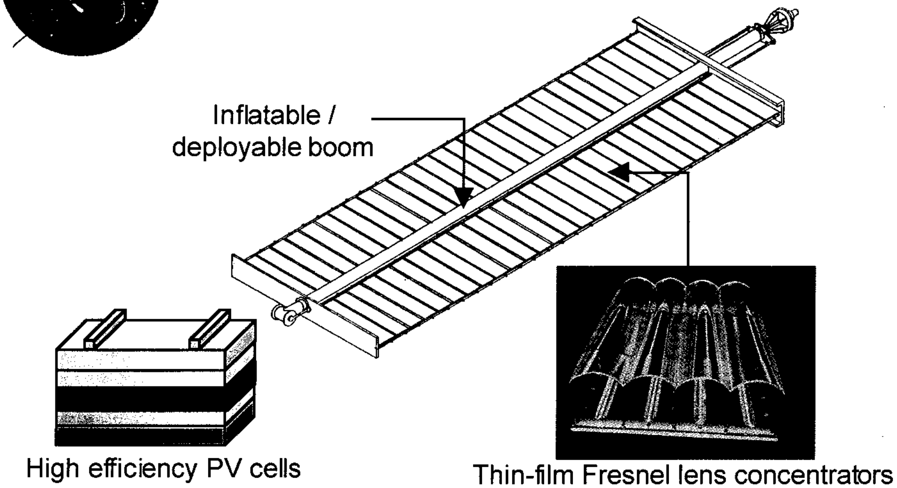


Potential Missions:
- ESS: NO
- SEC: SPI, ISP (GSRI, Sub-L_1S, PASO, SF, IHC, OHRI, ISTB)

Flight Validation Rationale:
- Reduce risk for future sail missions by demonstrating deployment of large sail in microgravity environment.
- Microgravity deployment dynamics cannot be simulated in ground testing.
- Characterize structural dynamics of deployed sail to validate analytical models developed in ground testing.
- Assess the combined effects of the space environment on sail shape. Environmental effects include solar radiation pressure, microgravity, static charging, and thermal deformations.

Preliminary Cost Range/Validation Concept:
- \$6M - \$8M
- Shuttle Hitchhiker attached payload

Lightweight High Voltage (LHV) Solar Array



Technology Requirements:

- 7.5kW design
- >175 W/kg at 1 AU, capable of operating at 5 AU
- 300V output for high voltage applications, e.g., Solar Electric Propulsion

State of the Art:

- Specific power of DS-1 SCARLET array is 44 W/kg at 100V output

Potential Missions:

- **ESS: CNSR, NO, SRO, TE, VSSR**

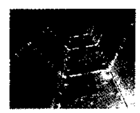
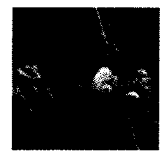
Flight Validation Rationale:

- Demonstrate zero-gravity deployment of the array and of solar concentrator optics.
- Characterize the structural dynamics of the ultra-lightweight array, and interaction between the flexible array and spacecraft dynamics.
- Demonstrate high-voltage (300V) operation of advanced PV cells in space plasma environment, and validate methods to control static charge accumulation and arcing.

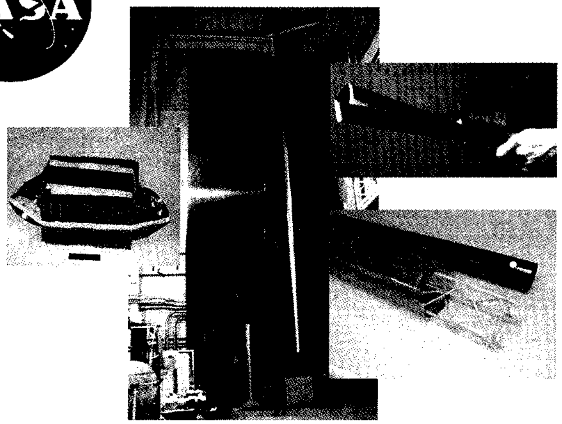
Preliminary Cost Range/Validation Concept:

- $4M - $12M
- Shuttle Hitchhiker attached payload

Solar Array Roadmap

1998	2000	2005	2010
		NMP	
			
DS-1 SCARLET Array 44 W/kg	Hughes HS702 Array 70 W/kg	LHV Array Flight Validation 175 W/kg	Future SEP Missions (CNSR) 200 W/kg

Deployable and Inflatable Booms



Technology Requirements:

- Ultra-lightweight booms required for solar sails, large apertures, and sunshields
- Test variety of structural concepts, length/diameter ratios, and rigidizable materials.
- Length > 20m
- Mass/length <50g/m
- Multiple deployments to demonstrate reliability.

Potential Missions:

- **ESS: NO**
- **SEC: GEC, RAM, SPI, (GRSI)**
- **SEU: ARISE, CON-X, SPIRIT, OWL**
- ASO: TPF, FAIR, LF, SUVO

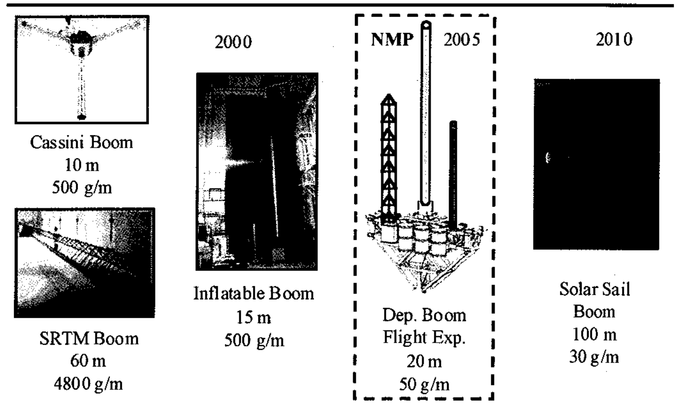
State of the Art:

- Length = 60m (SRTM antenna mast)
- Mass/length = 500g/m (Cassini magnetometer booms)

Flight Validation Rationale:

- Characterize deployment dynamics of long booms in microgravity environment. Microgravity deployment dynamics cannot be simulated in ground testing.
- Demonstrate uniformity and completeness of rigidization in the space environment. Rigidization could be affected by microgravity, extreme temperatures, and UV radiation.
- Characterize the structural mechanics and dynamics of deployed booms in microgravity environment to validate analytical models developed in ground testing.

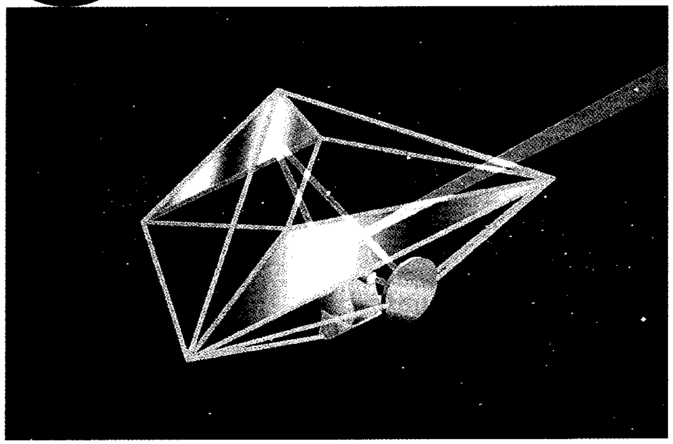
Deployable Boom Roadmap



Preliminary Cost Range/Validation Concept:

- $3M-$5M
- Shuttle Hitchhiker attached payload

Membrane Optics Deployment



Characterization of Factors Limiting Mirror Surface Precision

Technology Requirements:
- 1- 2m diameter aperture
- Areal density ~1kg/m^2
- Metrology system to characterize mirror surface figure

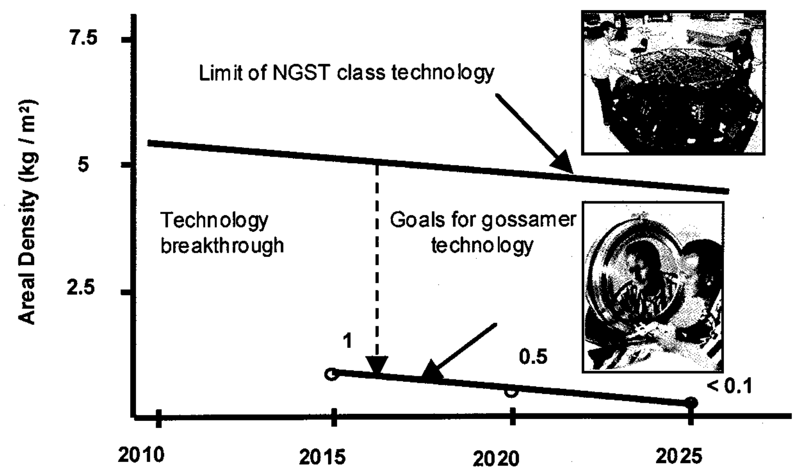
State of the Art:
- Areal density target for NGST is 15kg/m^2
- Proof-of-concept membrane optics (~1kg/m^2) are being developed in laboratory

Potential Missions:
- SEC: (SISP)
- SEU: CON-X, HIS, MAXIMPF, SPIRIT
- ASO: FAIR, LF

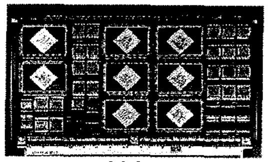
Flight Validation Rationale:
- Characterize the factors limiting achievable mirror surface precision such as deployment errors, microgravity effects, and thermal deformations. These characterizations are essential for designing adaptive optical systems to control mirror shape and correct wavefront errors.
- Validate packaging and deployment concepts for membrane optics.

Preliminary Cost Range/Validation Concept:
- \$4M-\$8M
- Shuttle Hitchhiker attached payload

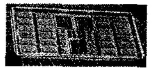
Lightweight Optics Roadmap



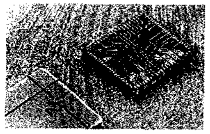
Ultra Low Power (ULP) Advanced Electronics



1986
Global Bulk Memory
12.7x22.9x1.5 cm
9.2 Mbits, ~70 W



1993
Global Bulk Memory MCM
5.08x10.2x0.64 cm
9.2 Mbits, ~20 W



1999
256 Mbit Memory Cube
0.76x0.76x0.43 cm ~1 W

Potential Missions:

- ESS: CNSR, EL, NO, SRO, MSR, TE, VSSR
- SEC: GEC, MC, (SN)

Flight Validation Rationale:

- Decreasing feature size and increasing complexity of advanced semiconductor components leads to higher sensitivity to SEU effects
  - Interactions between parts of a subsystem difficult to characterize
- In flight test provides extension/validation of ground test models and error detection/correction techniques

Preliminary Cost Range/Validation Concept:

- \$5 M to \$15 M
- Earth orbit in the radiation belts for at least one year

Technology Requirements:

Non-Volatile Memory
- 8 Gbits at <1 Watt max, <200 grams

Serial Bus
- >5Mbps data rate at < 2 watts max

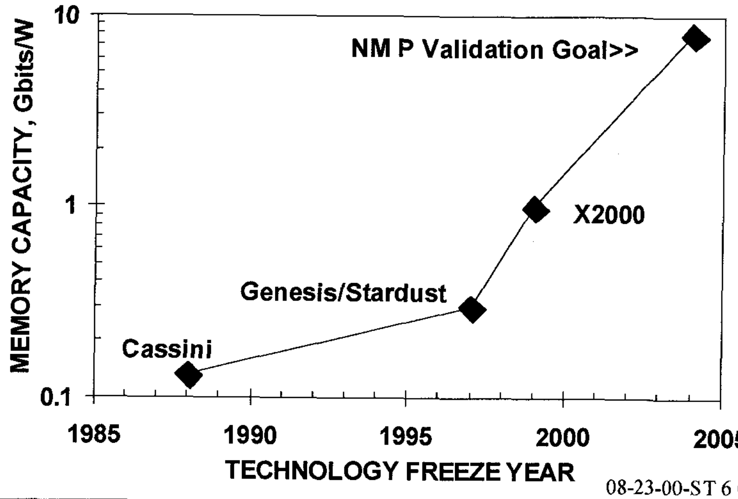
High Performance Processor
- >300 MIPS at < 2 watts max

State of the Art:

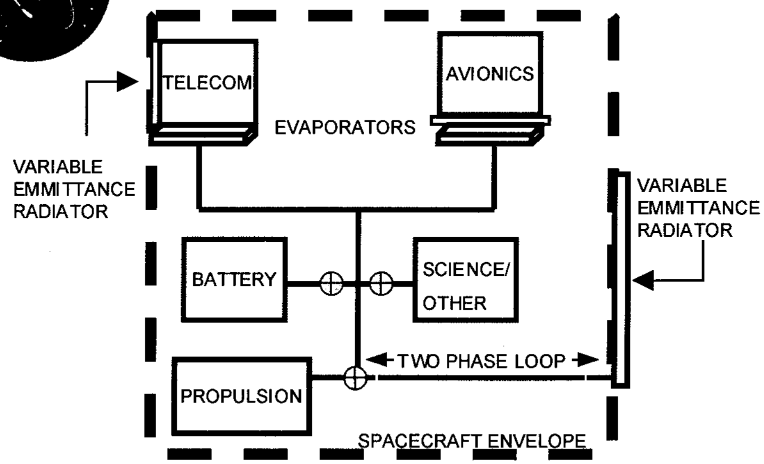
Non-Volatile Memory
- 8X more memory per Watt, 5X more memory per gram

Serial Bus
- 80% less power, 5 times higher data rate

High Performance Processor
- 80% less power, 20% higher processing capability, higher reliability



Miniature Energy-Saving Thermal Control Subsystem



Technology Requirements:

- Demonstrate energy savings by moving heat from hot to cold components.
- Two phase passive loop to transport 50W from hot to cold components
- Incorporate control features:
  - to switch heat transfer path when the heated component is above the control temperature limit.
  - variable emittance device on Radiator modulates rejection of heat to space.

Potential Missions:

- ESS: CNSR, NO, TE

Flight Validation Rationale:

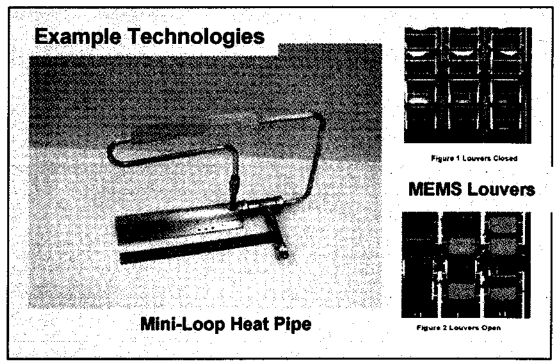
- Two phase fluid flow of miniature transport loop must be tested in microgravity conditions.
- Risk of implementation shift to new energy saving concept mitigated by flight validation.

Preliminary Cost Range/Validation Concept:

- \$3M to \$5M
- Tests in microgravity environment by measuring the properties of a number of two phase heat transport devices and variable emissivity devices.

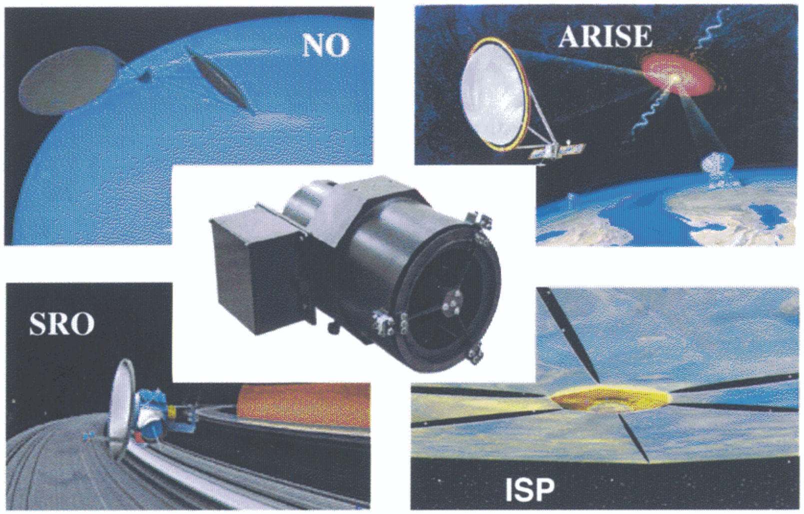
State of the Art:

- Heat from hot components rejected to space
- Spacecraft power/heater used to warm cold components
- Energy-saving thermal control subsystem reduces spacecraft power demand and mass by ~15%
- Provides 10 fold reduction in mass over current thermal control subsystems.



Wideband Optical Communications

NMP



Technology Requirements:

- Data rates: 1-10 Gbps, weight: <40kg, power:<70W, volume: <12,000 cm3
- Acquisition, tracking and pointing for near earth to interplanetary ranges.
- High efficiency optical communications system

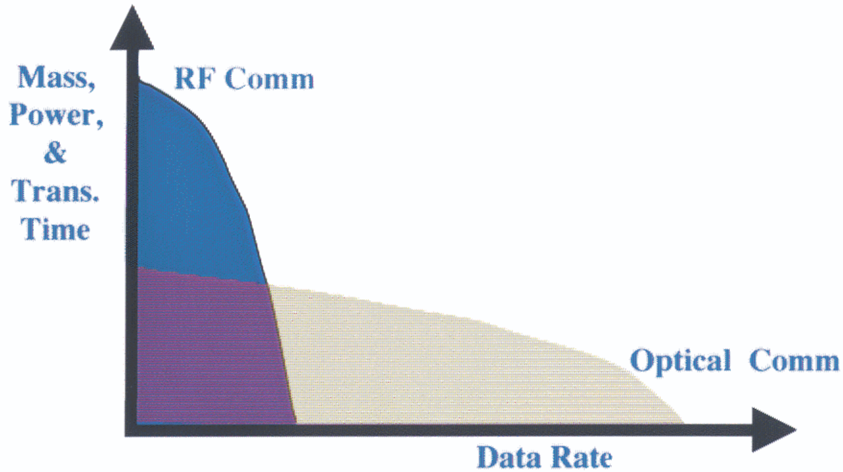
State of the Art:

RF as Compared to Optical

- Data rate: 10 times less
- Power consumption: 3 times greater
- Aperture size: 10 times greater
- Mass: 2 times greater

Optical

- Lab and Ground station to station demonstrated



Potential Missions:

- ESS: CNSR, NO, SRO, EL, VSSR
- SEC: ISP
- SEU: ARISE

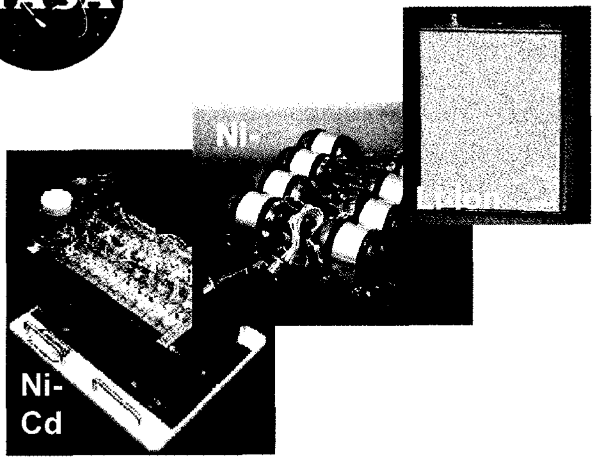
Flight Validation Rationale:

- Communications Paradigm Shift
- Cloud attenuation and other Atmospheric Effects
- Space-Ground Microradian Beamwidth Acquisition, Pointing and Tracking

Preliminary Cost Range/Validation Concept:

- $10M to $15M
- Near-earth or interplanetary environment for least one year

Secondary Batteries for Deep Space Missions



Technology Requirements:

Requirement	Type I	Type II
Cycle Life	>30,000	>300-500
Shelf Life	>7 yr	>15 yr
Depth-of-discharge (DOD) max	20-60%	80%
Radiation	0.1 Mrad	1 to 10 Mrad
Specific Energy Goal (100% DOD)	150 Wh/kg	
Amp-hour Capacity	5 to 50 Ah	
Charge-Discharge Energy Efficiency	>90%	
Normal Operating Temperature	-10 to +30°C	
Extreme Operating Temperature	-20 to +50°C	
Voltage Range	22 to 36 V	

Potential Missions:

- Deep Space Missions

Flight Validation Rationale:

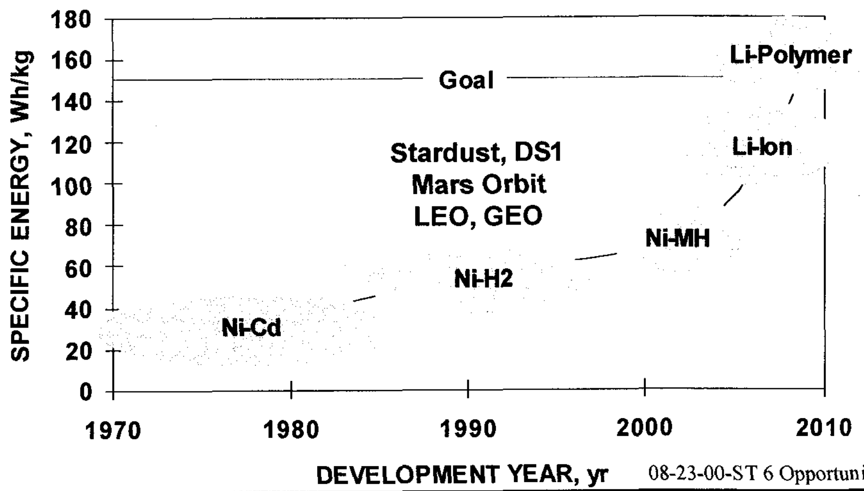
- Determine if new battery performance is affected by microgravity, which can lead to electrolyte differentiation and degradation in battery operation.

Preliminary Cost Range/Validation Concept:

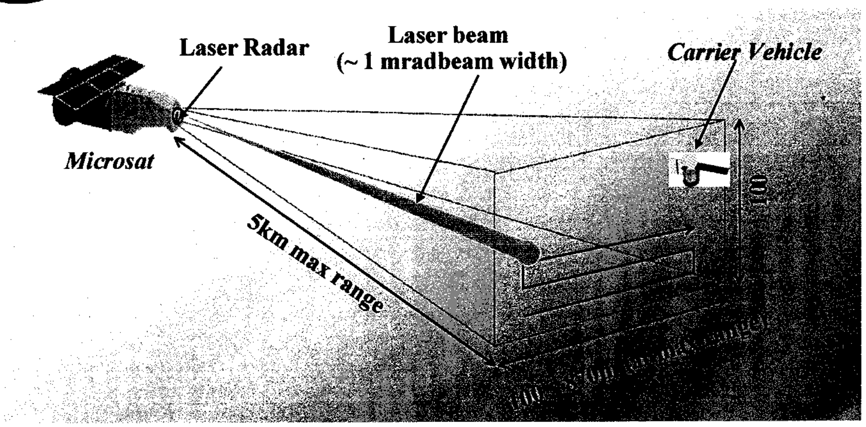
- $2M to $3M
- Operate batteries in space under extreme conditions, such as temperature and DOD
- Measure battery cell parameters
- Quantify effect of extreme conditions and microgravity on battery performance.

State of the Art:

- 3 to 5 times the specific energy (Wh/kg) of Ni-H2
- 1/10 the volume of Ni-H2 batteries



Autonomous Rendezvous



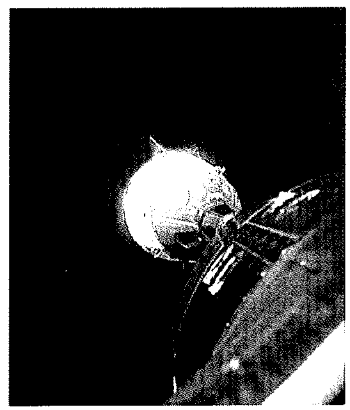
Potential Missions:
- **ESS: CNSR, MSR, VSSR, EL**
- ASO: Potential TPF

Flight Validation Rationale:
- Three dimensional orbital dynamics & drag-free environment not realizable in ground facilities
- Verify subsystem functionality under variable ranges, configurations and geometries

Preliminary Cost Range/Validation Concept:
- \$10M-\$15M
- Fly an active sensor package on a maneuverable host vehicle
  - characterize sensor performance
  - provide the host vehicle with target information
  - validate several types of control algorithms
  - assess mission support requirements

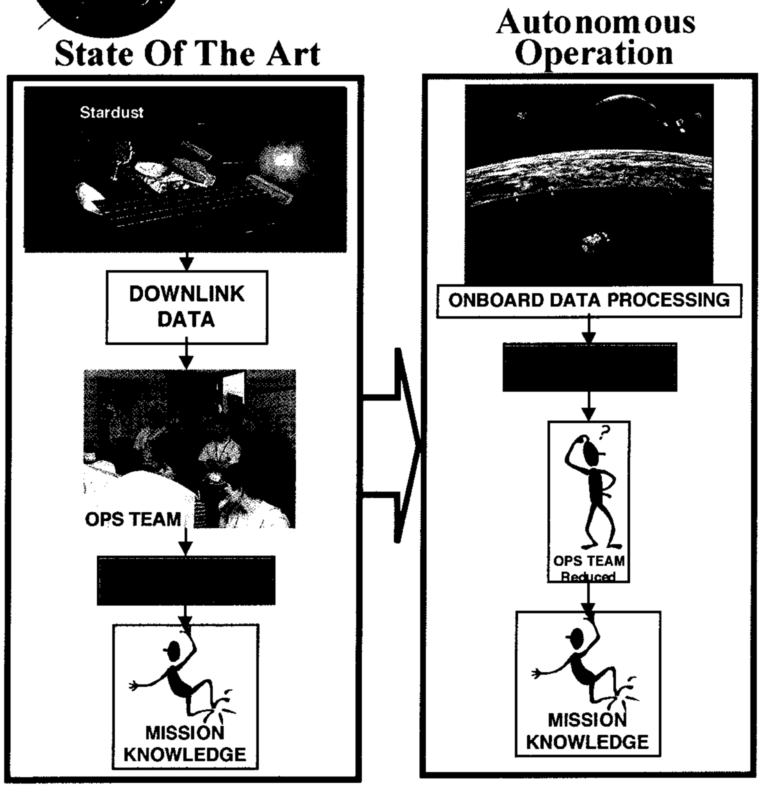
Performance Requirements:
- Operating Range: 5km to 0.5m
- Accuracy at 2 Hz sample rate:
  - 5m (Range 5 to 2km);
  - 0.25% range (Range 2km to 10m);
  - 2.5cm (Range < 10m).
- Range and Transverse Rates: 1-10cm/s.
- Mass: <4kg; Power: <25W

State of the Art:
- Current technology requires extensive ground interaction and space-borne sensors weighing tens of kilograms consuming hundreds of watts.
- New low mass, low power sensors have been demonstrated in ground tests
- Algorithms for data analysis and control have been simulated in mission contexts



Onboard Data Processing to Reduce Downlink & Mission Operations Staff

NMP



Technology Description:

Onboard software capable of:

- Sensor data-fusion for guidance navigation and control
- Onboard resource management and optimization
- Onboard re-targeting to repeat science observations
- Real-time path re-planning and hazard avoidance
- Capture serendipitous science

Performance Metrics compared to State-of-the-art:

- A ten fold reduction in required down-link data rate
- A 50% reduction in mission operations staff
- A 50% reduction in setup-time for science observation

State-of-the-art Capabilities are limited to:

- Onboard calibration and error correction of sensor data
- Limited data fusion requiring ground interaction
- Pre-programming for simple processes

Technology Validation Rationale:

- Implementation paradigm shift from ground to onboard data-driven decision making
- Requires complex interactions between spacecraft assets, states, resources and space environment

Applications:

All missions that:

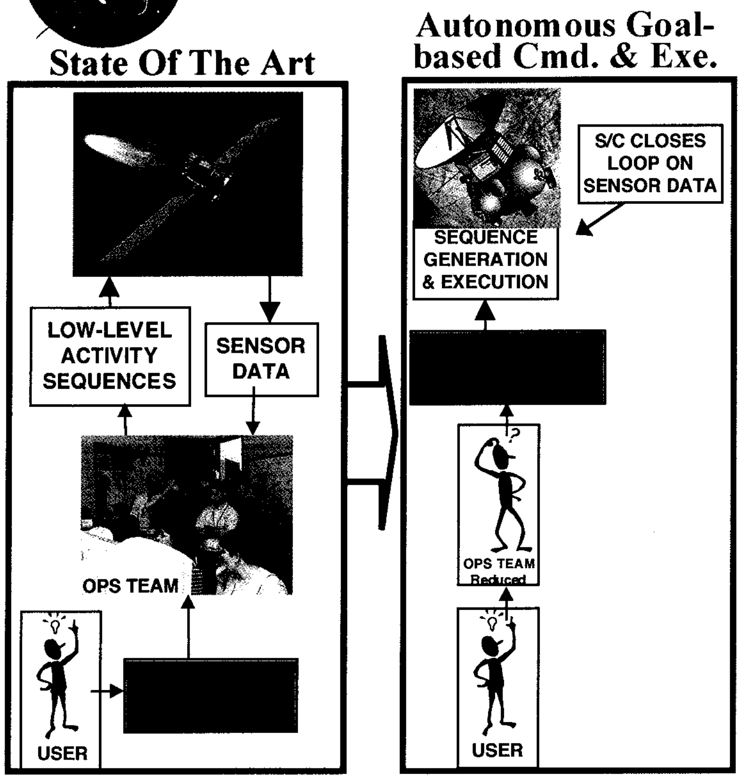
- Has coordinated multiple spacecraft operation
- Operate over long distances, long periods and in harsh environments (temperature, radiation, pressure)
- Adapt to unknown and/or changing conditions

Such as: **ESS: CNSR, EL, NO, SRO, TE, VSSR**
SEC: GEC, ISP, MC, MMS, RAM, RBM, (PASO, SN)
SEU: ARISE, CON-X, OWL

Preliminary Cost Range: $1M - $5M.

Validation Concept: A mission rich in complex tasks requiring event-triggered activities.

Autonomous Goal-based Mission Commanding & Execution



Technology Description:

Onboard mission activity planning software for:
- Autonomous operations in unpredictable environments
- Dynamic planning and plan optimization

Performance Metrics compared to State-of-the-art:
- A five fold workforce reduction for Cassini-class mission operations
- Quantifiable plan development time
- Resource requirements restricted to be the same as planned by traditional systems

State-of-the-art Capabilities are:
- Experimental and dependent on artificial intelligence experts to implement and operate, example: remote agent experiment on DS1.

Technology Validation Rationale:
- Implementation paradigm shift to onboard decision making and task decomposition
- Requires complex interactions between spacecraft assets, states, resources and space environment

Applications:

All missions that:
- Has coordinated multiple spacecraft operation
- Operate over long distances, long periods and in harsh environments (temperature, radiation, pressure)
- Adapt to unknown and/or changing conditions

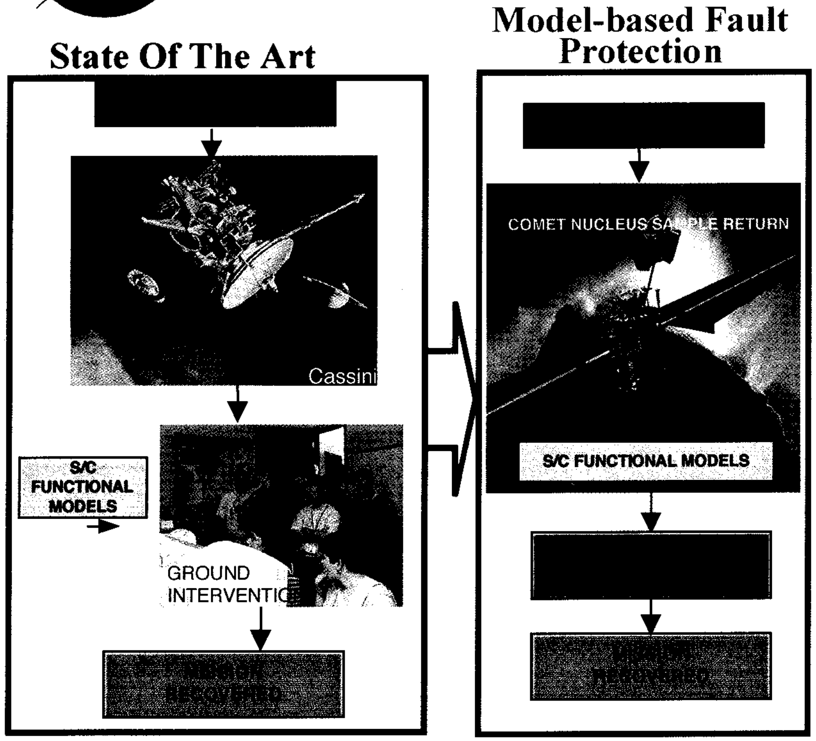
Such as: **ESS: CNSR, EL, NO, SRO, TE, VSSR**
SEC: ISP
SEU: OWL, MAXIMPF

Preliminary Cost range: $1M - $5M.

Validation Concept: A mission rich in complex tasks requiring event-triggered activities.

Model-Based Fault Protection for Complex Systems

NMP



Technology Description:
- Software for Automated monitoring, diagnosis and recovery
- Provides Reasoning based on on-board models of spacecraft functions
- Replaces procedural elaboration "if…then…" approaches.

Performance Metrics compared to State-of-the-art :
- Limit safing to complete subsystem failures
- Computational resources are restricted to be commensurate with current spacecraft capabilities

State-of-the-art Capabilities are limited to:
- Autonomous switching between redundant components
- Pre-programmed critical sequences, example Cassini

Technology Validation Rationale:
- Implementation paradigm shift to onboard decision making for mission robustness
- Requires complex interactions between spacecraft assets, states, resources and space environment

Applications:

All missions that:
- Has coordinated multiple spacecraft operation
- Operate over long distances, long periods and in harsh environments (temperature, radiation, pressure)

Such as: **ESS: CNSR, EL, NO, SRO, TE, VSSR**
SEC: **RAM, SDO, ISP**
SEU: **ARISE, CON-X, OWL**

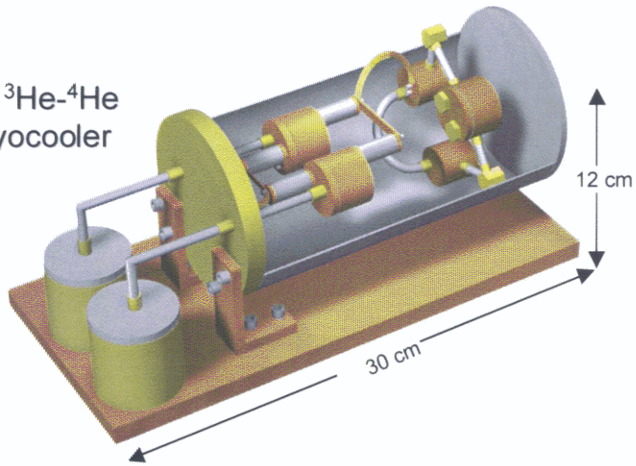
Preliminary Cost range: $1M - $5M.

Validation Concept: A mission rich in complex tasks requiring event-triggered activities.

Dilution Cryocoolers

NMP

Continuous ^3He-^4He Dilution Cryocooler



Technology Requirements:

- Cooling: 50 mK to 300 mK, Stability: ~ 10 µK
- Mass: <10 kg, Lifetime: >2 yrs

State of the Art:

- Magnetic coolers require magnets that add mass and can interfere with science measurements.
- Planck's High Freq. Instr. uses a 0.1 to 1.6K open-loop cooler with stored cryogen and so has finite life.
- Only dilution coolers require flight validation due to effects of gravity on their liquid coolants.

Potential Missions:

- Cooler suitable for calorimeters for mm and submm wave detection and bolometers for X-ray detection.
- SEU: CON-X, SPIRIT, MAXIMPF, (ACT, SPECS)
- ASO: FAIR, SUVO

Flight Validation Rationale:

- Dilution cryocooler may not work in micro-gravity due to an inability to confine the helium liquids to their chambers.

Preliminary Cost Range/Validation Concept:

- $5M to $10M
- Validate gravity independence of dilution cryocooler.
- Determine power needed to achieve lowest temperature.
- Demonstrate compatibility with calorimeters and bolometers.